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CARTOGRAPHIC DATA RETRIEVAL, ANALYSIS, DEPICTION, PRESENTATION AND PRODUCT GENERATION: GEOGRAPHICAL INFORMATION SYSTEMS

How to benchmark your geographic information system

Paper submitted by the United States of America**

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HOW TO BENCHMARK YOUR GEOGRAPHIC INFORMATION SYSTEM

Geographic information systems (GIS) are emerging as the spatial data handling tools of choice for solving complex geographic problems. However, few guidelines exist to help potential users identify suitable hardware and software. Users must evaluate the merits of GIS technology according to standards and guidelines, software functions, hardware components, and benchmark testing, which identifies optimal hardware and software. By making users aware of all aspects of adopting GIS technology, they can decide if a GIS is an appropriate tool for them and which GIS should be used.

HOW TO BENCHMARK YOUR GEOGRAPHIC INFORMATION SYSTEM

Some users feel that independent testing and rating of GIS, much like evaluations of personal-computer software by InfoWorld magazine, would aid their decisionmaking. Although independent testing may be useful for some types of evaluation, the user of GIS technology must be deeply involved in the evaluation process. Why is this the case? First, the process of benchmarking a GIS is a complex, difficult, and potentially expensive task. Second, and more important, GIS benchmarks should be driven by user requirements. In the end, users must benchmark their systems. This article will examine various components of GIS benchmarking, review what independent testers of GIS technology can provide, and discuss what users should do.

User Requirements

GIS technology is successful when it meets users' needs comprehensively and consistently. Development of a successful GIS depends on well-defined user requirements; therefore, a user requirements analysis should be performed. The analysis should identify the operation, users, and data requirements of the existing system; identify potential uses and users of the GIS; define digital and hard-copy products required; evaluate work flow; estimate data base requirements that support GIS implementation; refine GIS product characteristics; calculate necessary production rates; and estimate data volumes. The analysis should also include a cost/benefit study.

The user requirements analysis documents how an organization functions and supports its users, and quantifies and defines an alternative operation on the basis of GIS technology. It does not address such issues as the organization's objectives, goals, or staff capabilities, which are not quantifiable technical issues. However, such factors could override conclusions based solely on technical considerations.

If, upon completing such an analysis and assessing the appropriateness of GIS for the organization's missions, it is determined that GIS technology should be used, evaluation criteria must be devised for selecting a specific GIS. The evaluation criteria should be incorporated in the specifications for benchmark testing.

Hands-on experience with GIS capabilities is valuable in developing evaluation criteria. One method for acquiring such experience is to perform a small-scale pilot project. The pilot project should be designed to test the ability of GIS technology to meet an organization's needs. Pilot tests are a source of realistic

data on production rates, memory and storage requirements, and user response to GIS products. Pilot test results can also be used to refine evaluation criteria that were derived from the user requirements analysis.

All or part of the GIS designed for the organization may be tested, depending on the organization's familiarity with GIS. Testing only portions of the GIS that are most critical to organizational needs, or that represent the elements with which the organization is least familiar, may be desirable.

Identification of GIS Functions

Defining processing functions to meet specific needs is an important step in the design and evaluation of a GIS and is a direct outgrowth of the user requirements analysis. Identifying required functions often begins with a detailed list of GIS products and their specifications. Further analysis leads to identifying the type of processing functions needed to produce each product. My paper on evaluating GIS (1988, see references) includes a checklist of GIS software components.

Mandatory and desirable individual processing functions should be identified. Mandatory software capabilities, when merged with such specific application needs as required response time, accuracy, precision, product-generation frequency, and data volumes, lead directly to mandatory hardware capabilities.

Existing GIS's are extremely diverse in function and data base structure. Systems use various methods for digitizing, assigning, and storing attribute, coordinate, and topological information. The capability to manipulate, analyze, and display this information varies among systems. Capabilities of a given system are often oriented toward a specific function or application, such as computer-aided design and mapping, surveying, natural-resource management, terrain analysis, or image processing. Users must find the best match of system capabilities and user requirements. This is where benchmark testing can help.

Benchmarking is a process in which computer systems such as GIS are tested for function and performance. Benchmarking is accepted as part of the acquisition process by both private industry and the federal government. The success of benchmarking depends on the extent to which tests can be constructed that are representative of expected workloads. The following ten procedural steps for benchmark construction are described in Federal Information Processing Standard Publication 75, Guidelines on Constructing Benchmarks for ADP System Acquisition (U.S. National Bureau of Standards, 1980):

Step 1. Define benchmarking objectives and complete such preliminary activities as defining an agency's service, operational, and workload requirements.
Step 2. Quantify the present workload requirements.
Step 3. Obtain information from users on present applications and user forecasts of new or changing applications.
Step 4. Estimate future workload requirements.
Step 5. Categorize future workloads into distinct categories.
Step 6. Determine the relative contribution of each category.
Step 7. Scale each category. Weight the running times for each category's set of benchmarks according to its contribution.
Step 8. Represent workload categories with benchmarks. Select programs that represent the workload categories identified in step 5.
Step 9. Fine tune the mix of benchmarks on the present system.
Step 10. Prepare the benchmarking package, which consists of documentation of the mix of benchmarks and rules for the live test demonstration, and test the benchmarks.

A key point is that benchmarking must be done on products and capabilities identified through a user requirements analysis and must reflect estimated future data volumes. Users must also recognize that the preparation of a comprehensive benchmark may be a major task. Factors such as the size of the procurement must be weighed against the effort required to conduct benchmarking, and then a decision can be made on the appropriate level of testing.

What to Test

The functions of GIS can be grouped into five categories: user interface, system/data base management, data base creation/data entry, data manipulation and analysis, and display and product generation. It is possible to develop function and performance requirements for each of these areas.

The user interface is the way operators communicate with the data base and GIS application modules. It consists of such software capabilities as menus, help screens, and graphic displays that simplify and organize the interaction between user and GIS software.

The data base management component provides the environment in which the GIS functions and the means by which the data are controlled. The system management environment is furnished by the operating system of the host computer. GIS data base functions parallel those of a non-spatial data base management system (DBMS), but with extensions beyond the addition, deletion,

revision, and Boolean retrieval capabilities of a standard DBMS. The GIS DBMS contains hardware and software facilities for storage, retrieval, and update of spatial information in alphanumeric and digital graphic forms, and incorporates storage structures to minimize data redundancy and to aid spatial searches. In addition, the GIS DBMS must have file management capabilities to handle a potentially large archive of geographic data files.

Data base creation/data entry refers to the process of bringing data into the GIS environment. A GIS data base contains a series of thematic categories or topics (layers) of information. These layers may contain information captured from aerial photographs, remote-sensing images, conventional maps, or other sources.

Data entry is the process of loading data into a GIS data base. Data in a computer-compatible format, such as digital remotely sensed data, can be loaded directly. A data base may also be created by digitizing or scanning maps or by digitizing information on aerial photographs to create a computer-readable data set. This effort is sometimes referred to as data capture.

Two types of data are generally collected: locational or geographic and accompanying feature attribute data. Locational information is usually digitized from existing graphics, maps, or images. Attributes identify what the features represent in the form of numeric or textual information such as soil type, feature name, or road class.

If spatial information capture and management are performed properly, the accuracy of the data will be maintained. The GIS user may then proceed to the primary GIS activities, data manipulation and analysis. Spatial analysis tools are used to model, make predictions, and reach conclusions about problems. Such analysis involves combining data from multiple spatial data categories and performing analytical, statistical, measurement, and other operations on the GIS data sets to transform the data into information suitable for a given application. Spatial analysis techniques include compositing areas, performing proximity searches, analyzing networks, and clustering and aggregation operations. These operations are ideally performed in an interactive mode on the spatial component of the data, as well as on non-spatial attribute data. Such operations can range in complexity from simple Boolean queries to reclassification and creation of new map displays.

The typical GIS has capabilities for display and product generation. Maps, charts, graphs, and tables can be produced, and displays can range in complexity from tabular reports and simple monochrome plots to publication-quality, three-dimensional color graphics.

GIS hardware components can be divided into six major categories of devices: data capture/input, processing, communications/networking, interactive display and edit, external storage, and hard-copy output. These categories can be further divided into hundreds of hardware components used in an information processing system. Hardware components can be tested against a number of measures: performance (speed of the central processing unit, rate of graphics display), accuracy (precision of a digitizing table, resolution of a plotter), and capability (maximum plot size, disk storage size). The total specification of all aspects of GIS hardware is laborious and probably not required. Users should focus on aspects of hardware specifications that directly affect performance.

Testing

Once users decide what to test, they must consider how to perform the testing. Do they test a specific function such as polygon overlay with or without sliver removal, or do they test a number of system components simultaneously? For example, the Structured Query Language (SQL) statements that follow test a variety of system components including the ability to optimize queries, the effectiveness of indexes, and the performance of the spatial operator WITHIN. This series of statements asks the GIS to find all public schools located within areas of high radon concentration.

```
SELECT *
FROM BLDG
WHERE BLDG.LOC WITHIN RADON.POLY
    AND BLDG.LOC IN
        (SELECT BLDG.LOC
        FROM BLDG
        WHERE BLDG.TYPE = 'PUBLIC SCHOOL')
    AND RADON.POLY IN
        (SELECT RADON.POLY
        FROM RADON
        WHERE RADON.POT > 4.0)
```

Another factor to consider is accuracy. How do users know if the results are correct? One way is to test GIS functions with mathematically generated data sets for which correct answers are known. For example, two sets of concentric ellipses could be intersected as one test of the correctness of a polygon overlay operation.

Users must also remember that test results are dependent on the data sets used. "Stress testing" systems with large data sets may reveal problems. Systems that behave well with modest-size data sets may rebel when processing large data sets.

The Bottom Line

The traditional methods of acquiring, storing, and analyzing spatially referenced data are becoming too costly and inflexible in meeting today's information requirements. Even so, potential users of GIS should understand all aspects before adopting this new technology. Is GIS an appropriate tool for the intended application, and if so, which GIS should be used?

Users and independent testers can work together to provide answers to this question. Users must ensure that the system has the software functions required to support their applications, and that their hardware configuration is adequate to support their software and provide a path for growth. Independent testers should ensure that key GIS functions produce accurate results, and should "stress test" key GIS functions by using a standardized set of test data.

Evaluating GIS technology will help managers and technical specialists understand GIS technology from a realistic perspective.

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